§62. Hot Electron Transport in Targets Deduced from the Electron Spectral Measurement on FIREX

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The hot electron behaviors in laser irradiated targets for the fast ignition (FI) have been experimentally studied by the electron spectrometer (ESM) [1] and by the PIC simulation. (i) Usage of the hot electrons with the low effective temperature T_{eff} ,which is the trend in the recent FI scheme using the cone-guide target, is not suitable to realize the FI due to the effect of collective behaviors (current), (ii) The results in the integrate experiment suggest that the lower T_{eff} components do not heat the core sufficiently. (iii) The new target in which the low T_{eff} components are effectively utilized, should be designed for FI.

In the lower T_{eff}, the higher coupling efficiency ε_c has been thought to be expected in the cone-guide target because the range of the hot electron is much larger than the areal density ρR of the core. However, the pre-pulse of the heating laser should decrease in order to achieve the lower T_{eff}. This means the laser absorption efficiency also decreases at the lower T_{eff} [2]. A hot electron current increases at the lower T_{eff} because the energy with the high energy tail of the hot electrons transfers to the lower electrons. Here, the electron transport in targets has been studied from the electron spectra in the vacuum region, which are obtained from the ESM.

Generally, the current is localized on the surface of a conductor when the high-frequency current flows in it. It is well known as "skin effect". The hot electron current created by the high intense short pulse laser has ultra-high frequency. When the T_{eff} decreases by suppression of pre-formed plasma, a huge current should appear if the total energy is preserved. At that time, the lower energy electrons are localized around the target surface due to the skin effect based on the time-derivative self-magnetic field $\partial B_{self} / \partial t$ same as the conductor. The phenomenon can be confirmed by the PIC simulation (plasma particle accelerated by laser field w/o collision). Typical energy distributions are shown. These (low) energy electrons (typically 25 % of the hot electrons, 10% of the laser energy) move along the surface due to the $E\times B_{self}$ drift, where the electric field E is produced by the induced electric field and the escaped electrons. On the contrary, the energetic electrons can penetrate the target and travel straight forward since the return current can be acquired easily. However the energetic electrons cannot heat the core effectively. Here we remark the low energy electrons and consider behaviors of hot electrons not only as a single particle but also as collective particles.

We can understand that the B_{self} is strongly related to the hot electron movements from several results in the LFEX laser (~1300J) irradiation experiment. When the low-Z material (diamond–like -carbon) is used, the T_{eff} is lower and the electron divergence angle Θ measured by the X-ray measurement, is wider (120°) than that of the high-Z material (gold, 20°). In the experiments, the T_{eff} has the inverse correlation against the Θ. This suggests that the Θ appears at the electron transport process rather than at the electron birth phase. These behaviors can be easily explained if the skin effect is introduced. According to PIC simulation, the energy spectra of the hot electrons can be approximated by a dual exponential profile. However, it is difficult to observe the low energy part of the electron spectra in targets directly. We can see it partially at the thick target because the electron current can be reduced by the absorption in the thick target . This fact is deduced because the electron behavior is related to the B_{self}. Another example is that the electron amounts measured by ESM increase when the external field B_{ext} is applied . The possible explanation of the experimental results is that the part of the trapped electrons by the B_{self} are guided by the B_{ext}. The electron spectrum, which are observed in vacuum region, are proved by the PIC simulation as shown [2]. The electron flux enhancement is remarkable at the higher energy region where the effect of the potential is relatively small.

The integrated experiments, in which the deuterated polystyrene shell targets are imploded by Gekko XII (GXII) laser and heated by LFEX auxiliarily, have been performed. Figure 1 shows the neutron yield N_y (measured by MANDALA) vs. T_{eff} and the GXII energy EGXII. The N_y increases with the EGXII. Although the imploded core cannot be observed clearly, the fuel can be expected to be gathered around the core if the EGXII is larger. Therefore higher ρR can be expected at the higher EGXII. The N_y decreases since the hot electrons penetrate the core with week interaction at the higher T_{eff} on same EGXII. The experimental results show that the higher N_y, that is, the higher εc, cannot be obtained at the lower T_{eff} on same EGXII. As mentioned above, the lower T_{eff} may deduce to the lower εc as a result due to the "skin effect". As a result, the m T_{eff} aximum of the N_y of 2.5x106 can be obtained at 6 MeV in the T_{eff}. This value is considerably higher than the simulation approximation.

The lower energy hot electrons may stay near targets and have a small contribution to the core heating considering the electron behaviors in PIC simulation. The utilization of electrons with lower energy is key to the suitable target design. One of the candidates is the inner shell irradiation target in the FI [3].

[1] T. Ozaki, et al., RSI, 83 (2014) 11E113.

[2] T. Ozaki, et al., IFSA2015.

[3] T. Ozaki, et al., Phys. Scripta, T161 014025(2014).

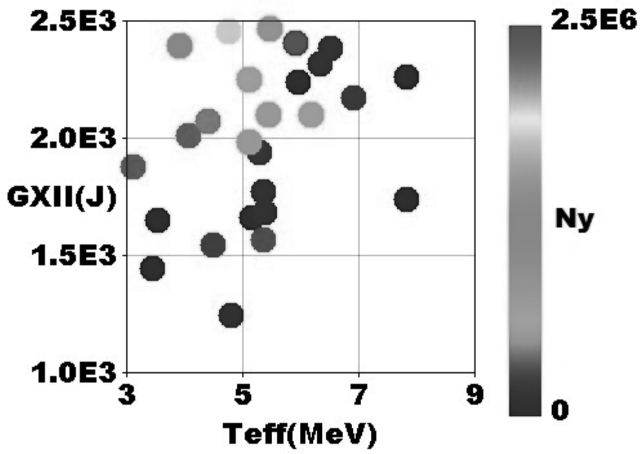

Fig. 1 N_y vs T_{eff} and GXII energy.
The maximum N_y an be obtained at 6 MeV, which is higher than the simulation result.